TECHNICAL INFORMATION SERIES

AUTHOR	SUBJECT CLASSIFICATION	NO.
R. P. Bass R. P. Bass	Bushings - Capacitors	50TP170
		DATE 7-10-50

TITLE

The Operation of 5 KV Glass and Porcelain Bushings in a Salt Fog Atmosphere

ABSTRACT

Glass and porcelain bushings

FOR USE OF G-E EMPLOYEES ONLY

GENERAL ELECTRIC

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The Operation of 5 KV Glass and Porcelain Bushings in a Salt Fog Atmosphere

ABSTRACT

Glass and porcelain bushings were tested in a salt fog atmosphere. Various types and quantities of salt were used. The mechanism of contamination and surface deterioration was studied. Means for the reduction of salt deposition and surface deterioration were developed.

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CONCLUSIONS 1. The greatest damage to bushings occurred when the salt fog contained a combination of sodium chloride and magnesium chloride.

2. The pitting of bushings used by P.G. & E. on their Pacific shore lines is caused by thermal shock resulting from arc discharges which play over their surfaces.

3. Mechanical shielding greatly reduces arcing, salt deposition and surface deterioration.

4. A coating of Teflon primer on a glass bushing eliminates surface deterioration and reduces arcing and salt deposition.

5. The surface deterioration of glass bushings can be reduced by a change to a low expansion glass.

6. Within practical limits neither size nor contour separately or together can prevent arcing, salt deposition and surface deterioration.

7. Increased bushing size reduces the severity of surface deterioration.

By cutting out this rectangle and folding on the center line, the above information can be fitted into a standard card file.

For list of contents-drawings, photos, etc. and for distribution see reverse side.

INFORMATION PREPARED FOR High Voltage Bushing Division

TESTS MADE BY B. J. Murphy, R. P. Bass

COUNTERSIGNED *T.R. Walters 7/12/50* DIV. Laboratory, Electrical ~~Research Section~~

TRANSFORMER & ALLIED PRODUCT DIVISIONS PITTSFIELD

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CONTENTS OF REPORT

NO PAGES TEXT 21

NO CHARTS

DRAWING NOS.

Figures Nos. I through XVI

Figure No. III 101HC675

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Table of Contents

	Page
Introduction and Scope	1
Purpose	1
Summary of Results	2
Conclusions	2
Nature of Contaminant	2-4
Mechanism of Contamination	4-6
Mechanism of Surface Deterioration	6-
Description of Material Tested	6-7
Description of Salt Fog Contamination Chamber	7-8
Method of Test	8-9
Results	9
Discussion of Results	9-12
A. Mechanical Shielding	9
B. Low-Coefficient of Expansion Glasses	10
C. Inorganic Coatings	10
D. Semi-Conducting Surface Coatings and Glazes	11
E. Bushing Contour	11-12
F. Miscellaneous	12
1. Bushing Position	12
2. Internal Heating	12
Summary of Results of Salt-Fog Tests	13-21

Introduction and Scope

One of the major problems in the operation of electrical apparatus with bushings exposed to air is that of obtaining trouble-free operation under conditions of severe atmospheric contamination. Some of the most difficult operating areas are found along the Pacific Coast where trade winds carry sea fogs inland. These fogs are usually the result of a condensation of water vapor around microscopic sea-salt "dust" particles evaporated from ocean spray.

The reports received from the San Francisco district office state that deposits of the salts carried inland by the sea fogs were visible on almost every object in the area including capacitor bushings. These deposits remain on the bushing surface for long periods of time and are only removed during the time of the annual rains. Coatings of salt and moisture on bushings result in surface deterioration, and flashover, and may even cause apparatus failures. The severe surface deterioration of glass bushings on 15 kvar power factor capacitors reported by the Pacific Gas and Electric Company was attributed to contamination of just this type.

This report summarizes the results of all the work performed to date by the Electrical Research Section in cooperation with the High Voltage Bushing Engineering Division on that phase of the general contamination problem concerned with the operation of bushings in a salt fog.

All tests were made on bushings designed for 15 kvar power factor capacitors delta connected on a 4160 volt circuit. Samples included standard G.E. glass bushings, standard G.E. porcelain bushings, competitors porcelains, and various modifications etc.

Purpose

The present project was undertaken to find ways:

1. To reduce or eliminate the deposition of salt on the surfaces of high voltage glass bushings,

2. To reduce or prevent surface deterioration,

3. To determine the mechanism of contamination and surface deterioration in order:

(a) To aid in determining when optimum performance has been obtained.

(b) To aid in improving performance by incorporating modifications in bushing design.

(c) To lay a foundation for future work on the problem of operating high voltage bushings in contaminating atmospheres.

Summary of Results

The fourteen photographs and the two blueprints grouped at the end of this report were selected to give a brief summary of the test apparatus used, characteristic salt deposits, and significant results of the tests conducted.

Conclusions

1. The greatest damage to both glass and porcelain bushings occurred when the salt fog contained a combination of sodium chloride and magnesium chloride. Figures IA and IB.

2. The pitting of bushings used by P.G. & E. on their Pacific shore lines is caused by thermal shock resulting from the arc discharges which play over their surfaces under the peculiar combination of atmospheric conditions encountered there.

3. Salt and moisture-coated bushings distribute voltage in proportion to surface resistance.

4. Mechanical shielding of the top three petticoats greatly reduces arcing salt deposition and surface deterioration. Figures VII and VIII.

5. A coating of Teflon on a glass bushing eliminates surface deterioration and reduces arcing and salt deposition. Figure XI.

6. The surface deterioration of glass bushings can be reduced by a change to a low expansion glass. Figure X.

7. Within practical limits neither bushing size nor contour, separately or together, can entirely prevent arcing, salt deposition or surface deterioration. Figure XIII.

8. Increased bushing size however reduces the severity of surface deterioration.

Nature of Contaminant

Reports from the San Francisco district office reveal that the principal contaminant on the capacitor bushings located near the seashore was salt. Although it has not been possible to obtain samples of the salt deposits for analysis, it may be readily assumed that they consist principally of the salts found in sea-water.

The percentages of the various salts contained in sea-water are given in Table I on the following page.

Table I

Composition of the Salt of Sea-Water *

Type of Salt	Percentages of Salt by Weight in Water: Standard Sea-Water	For Accelerated Tests
Sodium Chloride	2.69	10
Magnesium Chloride	0.32	1.2
Magnesium Sulfate	0.22	0.8
Calcium Sulfate	0.14	0.55
Potassium Sulfate	0.06	0.22
Others	0.01	--
Total	3.44	12.77

As may be seen from the table, the principle salt in sea-water is sodium chloride. It was for this reason that many of the early tests were performed using sodium chloride alone.

Early in the work it was found possible to accelerate the tests by increasing the salt content of the water used from 2.69 to 10 percent. However even with this increase, the length of time required to obtain tangible results was very long, varying from four to eight weeks. In an effort to reduce the run time further, a number of test runs were made using various combinations of salts as given in Table I in the column headed "For Accelerated Tests".

By the process of elimination it was found that the greatest damage to both glass and porcelain bushings occurred when a combination of sodium chloride and magnesium chloride were used. In fact the damage from this combination was far greater after one week on test than after four weeks with sodium chloride alone. This may be readily seen by comparing Figures IA and IB. Figure IA shows a standard 5 kv amber glass bushing after operating at 2.5 kv for four weeks in a salt fog containing 10 percent sodium chloride by weight. Figure IB in turn shows the results of operating a standard 5 kv amber glass bushing at 2.5 kv for one week in a salt fog containing 10 percent sodium chloride and 1.2 percent magnesium chloride by weight. This combination of the two chlorides has been used in every run since the above tests were conducted.

The reason for the exceptional reduction in test time made possible by the addition of only a small quantity of magnesium chloride may be understood

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* The values for standard sea-water are taken from Dorsey, N. Ernest; Properties of Ordinary Water-Substance - Table 289 on Page 655.

when two facts are remembered. First, magnesium chloride is extremely hygroscopic. It is the impurity found in common table salt which causes salt caking in table shakers. The second fact is that when this salt is heated sufficiently in the presence of water, the following reaction takes place:

$$MgCl_2 + 2H_2O \xrightarrow{\text{Heat}} Mg(OH)_2 + 2\,HCl\uparrow$$

The hydrochloric acid is driven off as a vapor and the magnesium hydroxide remains on the surface. This insoluble compound acts as a good binder for the sodium chloride and thus accelerates the accumulation of a layer of salt on the surface.

Figure II shows some characteristic salt deposits on various glass and porcelain bushings.

It has been established that the principle contaminant consists of the chlorides of sodium and magnesium. The following sections consider the mechanism of contamination.

Mechanism of Contamination

Along the seashore of the West Coast of the United States the particles suspended in the atmosphere consist principally of the various salts found in the sea. These particles are carried inland by fog or spray blown from the surf. The depth of penetration inland depends upon the topography and on the direction, strength and constancy of the prevailing winds which bring the salt particles within the electric field of the bushing.

The forces acting upon the air-borne salt and moisture particles are of several kinds, - aerodynamic, gravitational and electrical.

Aerodynamic Forces - The aerodynamic forces are of importance in the study of bushings operating under field conditions where the velocity and direction of the wind affects the density and positioning of the deposits. However in order to reduce the number of variables in the investigation no attempt was made to control the flow of air about the bushing. This has been reserved for future study.

The salt fog in the test chamber was in continuous motion with the result that each test sample was surrounded by a fog of reasonably uniform density. The tests conducted to determine the effect of sample position on the amount of contamination revealed that it made no difference where the samples were placed provided they were not too near the chamber walls.

Gravitational Forces - The gravitational forces determine the rate of settling of the larger particles and restrict the formation of deposits to the upper surfaces of bushings.

Electrical Forces - Tests show that the rate of salt deposition on bushings is greatly increased by the application of normal operating voltage. The deposits observed on unenergized bushings were merely the residue from the evaporation of the water remaining of the bushing surface at the end of a test run.

Mr. Wilson in his Data Folder 75509-IV A entitled "Derivation of Equations for Forces on Carbon Particles in A-C Electrostatic Field Surrounding Bushings" does an excellent job of deriving the expressions for the various electrical forces on carbon particles in oil near porcelain. These same equations are applicable to the field about a bushing in air.

The parameter which provides a measure of the effectiveness of the field in causing contamination is the ratio of the electric field force to the weight of the particle. Calculations based on Wilson's equations and on the voltage distribution of a 5 kv glass bushing, as shown in Figure III, give very low values for the ratio of force-to-weight. For a one micron salt particle and a field strength of 900 volts/cm. the force-to-weight ratio is approximately 10. Experience with carbon collection indicates that this value is rather low. However, this ratio is correct only so long as the bushing surface remains dry. As soon as the surface becomes coated with a conducting film of salt and moisture, the voltage distribution of Figure III is completely altered with the result that it becomes impossible to predict where the deposits will take place or what magnitude the force-to-weight ratios may assume.

The film of salt and moisture is not uniformly conducting over the surface of the bushing. When the film on one area of the surface is thinner than the rest a disproportionately large part of the voltage appears across this drier, high resistance area. If this voltage is sufficiently great, an arc occurs across this high resistance area. It has been observed that shortly after the beginning of each test run, the arcing occurs at random over the surface of the bushing. However as time passes one area predominates over all others. This results from the fact that arcing in any particular area causes evaporation which further increases the resistance of that area. This increases the frequency of arcing across this area and the accumulation of a salt deposit.

Observations over a long period of time (four to eight weeks) have shown that the phenomena described above apparently continues until a salt deposit is built up to such proportions that a bridge of salt is formed across the high resistance area. This salt bridge effectively short circuits the high resistance area. This increases the voltage drop on the other areas and the increased leakage current accelerates evaporation in those regions. This results in the formation of a new high resistance spot and shifts the

arcing to the new area. The original salt bridge is removed by the washing action of the fog.

This process produces a behavior such that one day a salt deposit may be on the first petticoat, the next day on the fourth, the next day the third, etc. The salt deposits never appear to prefer one area over another for more than a day or so.

It may be concluded that the process of contamination is aided by the electrical forces due to electrostatic fields. However these forces become significant only after the surface is coated with a film of salt and moisture. The utilization of these facts has made it possible to eliminate salt deposits, arcing and the resulting surface deterioration by the addition of a mechanical shield. This shield prevents the formation on the bushing of a film of salt and moisture which would otherwise connect the high voltage terminal to the ground flange.

Mechanism of Surface Deterioration

The pitting and chipping observed on the glass and porcelain bushings returned from the Pacific Coast has been duplicated in the laboratory under controlled conditions. This deterioration of the bushing surfaces was found to be caused by thermal shock resulting from the arc discharges spitting across the moist bushing surfaces. The heat of these arcs was sufficient to compress localized areas of the surface in excess of the strength of the glass or porcelain glaze and thereby cause chips to flake off.

Mr. H. Omley in his TIS report number 49TP284 entitled "Pitting and Etching of Glass Used in Bushing Manufacture" gives a detailed account of the tests conducted in the Glass Bushing Laboratory of the Analytical and Inorganic Section TAP Laboratory. These results prove that thermal shock is the cause of the damage to bushings rather than etching, weathering, corona decomposition or glass electrolysis.

Description of Material Tested

Bushings

1. Standard 2.5 kv centrifugally cast, amber, A50P69 glass bushings.
2. Standard 5 kv centrifugally cast, amber, A50P69 and 0-33 glass bushings.
3. Modified contour 5 kv centrifugally cast, amber, A50P69 glass bushings.
4. Modified contour 5 kv centrifugally cast, black, A50P69 glass bushings.
5. Five kv centrifugally cast, green, 1075 glass bushings.
6. Five kv centrifugally cast, black, A50P69 glass bushings.
7. Five kv Pheonix glass bushings.
8. Standard 8.7 kv centrifugally cast, amber, A50P69 glass bushings.
9. Proposed 15 kv center-clamped type L bushing shell.

Bushings (cont'd)

10. 14B948 multiple conductor glass bushing generally known as a "150BIL Bushing".
11. Standard 2.5 kv General Electric porcelain bushings.
12. Standard 5 kv General Electric porcelain bushings.
13. Glazed and unglazed General Electric porcelain bushings with contour to match modified contour 5 kv glass bushings.
14. 5 kv Westinghouse porcelain bushings.
15. 5 kv Cornell-Dubilier porcelain bushings.
16. 5 kv Line Materials porcelain bushings.
17. 8.7 kv Westinghouse porcelain bushings.
18. 8.7 kv Cornell-Dubilier porcelain bushings.
19. 15 kv General Electric smooth contour porcelain bushing.
20. 15 kv General Electric drip contour porcelain bushing.
21. Glazed and unglazed General Electric porcelain duplications of the proposed 15 kv center-clamped type L glass bushing shell.

Miscellaneous

1. Six glass rods eight inches long as follows:

	Rod Diameter	Coefficient of Linear Expansion x 10^6
(a)	1/4 inch	5.5
(b)	1/4 inch	5.03
(c)	1/4 inch	4.62
(d)	1/4 inch	4.04
(e)	1/4 inch	3.69
(f)	5/16 inch	3.38

2. Five 1/4 inch diameter glass rods eight inches long as follows:

	Rod Material	Coefficient of Linear Expansion x 10^6
(a)	Lime glass	9.2
(b)	#0-33 amber glass	5.5
(c)	PLF-3 amber glass	5.5
(d)	Pyrex glass	3.2
(e)	Vycor glass	0.8

Description of Salt Fog Contamination Chamber

A salt fog contamination test chamber, Figure V, was built to simulate the severe operating conditions encountered on 5 kv glass bushings on the Pacific Coast. This chamber, constructed of 3/4 inch Marine Plywood, has inside dimensions of: width - 28 inches, length - 50 inches and height -

35 inches. The top which is of a gable roof design adds another 12 inches to the height, thereby making the maximum inside height 47 inches. The front contains a sheet of 1/4 inch plate glass in order to permit visual observation of corona, etc.

A fan was installed which provides a maximum velocity of 20 mph at certain areas in the chamber. Two G.E. sun lamps were placed in the top to simulate sun light. Entrance bushings were provided for the high voltage and measuring leads.

The fog generator consists of a low pressure pneumatic atomizing nozzle. The nozzle is placed so as to obtain the maximum uniformity of fog density and velocity when the fan is inoperative. The liquid to be sprayed into the chamber is siphoned through the nozzle from an external supply tank. This permits maintaining a continuous supply of liquid without interrupting the test.

Associated equipment includes a transformer and control apparatus for varying from zero to 5 kv the voltage applied to the test sample. Also included is a plug board for the insertion of metering instruments between the ground flange of a bushing and ground. The electric counters used record the number of leakage current surges of over 10 ma.

Method of Test

The various glass rods, and glass and porcelain bushings were tested in the fog chamber shown in Figure V. The majority of the samples were placed on a platform fourteen inches above the floor of the chamber and at least ten inches from the side walls.

The first test run in the fog chamber of Figure V was started on November 12, 1948. Previous to that time, tests were conducted in a standard laboratory salt-spray chamber. The length of time per run varied from a minimum of about two days to a maximum of eight weeks.

All samples were clean and dry when placed in the fog chamber. Each run began with the application of voltage to the test samples following which the fog generator was started. The first eight test runs were conducted with an applied voltage to the test samples of 2.5 kv. Further tests proved that satisfactory results could be obtained, together with a reduction in test run time, by increasing the applied voltage to 5 kv.

The sample surfaces were examined frequently during a test run and the samples were removed from test after sufficient surface deterioration had been observed. The results of the examinations were recorded and in some cases photographs were taken. Also recorded on each run were such details as length of run, salt content of fog and applied voltage.

A standard eight-hour carbon run was made on six porcelain bushings of various types for the purpose of determining the areas of highest field stress. The following bushings were subjected to a voltage stress of 5 kv during the carbon run: 5 kv G.E. porcelain; 5 kv "W" porcelain; 8.7 kv "W" porcelain; 8.7 kv "C-D" porcelain; 15 kv G.E. drip contour porcelain; and a 15 kv G.E. smooth contour bushing.

Radio noise tests were made using the standard method described in NEMA Publication 107 on the following bushings: 5 kv G.E. porcelain; 5 kv "W" porcelain; 5 kv "C-D" porcelain; 8.7 kv "C-D" porcelain; 15 kv G.E. drip contour porcelain; 15 kv G.E. smooth contour porcelain; and a 5 kv G.E. modified contour glass bushing with modified hardware.

Results

1. The results of the carbon deposition test are shown in Figure VI. The areas of heaviest carbon deposition are located at the top around the terminal and at the bottom near the ground flange.

2. All of the bushings tested for radio noise were noise free at rated voltage except two, the 8.7 kv "W" with 14 microvolts and the 8.7 "C-D" with 25 microvolts. However, this is well within requirements.

3. The results of the various tests on samples in a salt fog conducted between September 3, 1948 and June 20, 1950 are summarized in Table II and are analyzed in the following sections. Photographs were taken of most of the bushings following test and are on file with the original data. Space permits reproducing only a small number of these pictures in the present report.

Discussion of Results

A. Mechanical Shielding - Bushings in which primary reliance was placed on maintaining dry zones by the addition of mechanical shields, as shown in Figures VII and VIII have proved exceptionally satisfactory in laboratory tests. These bushings remained free from arcing and thereby free from heavy salt deposits. As will be noted from the photographs, Figures VII and VIII, it makes no difference whether the shield is metal, glass or rubber. The important thing is that the seal between the shield and the bushing is water tight. This is readily appreciated when it is remembered that the function of the shield is to prevent the accumulation of water droplets on the bushing surface which will eventually run together and form a conducting path across the bushing. In all laboratory tests on water tight shielded bushings there has never been any noticeable increase in leakage current over the value obtained when the bushing was dry.

Figure VIII shows the results of the test on bushings with neoprene rubber shields. The shields were in the shape of a sink plunger. Figure VIII (a) shows the shield on a bushing and the rubber bird cap used to prevent

the accumulation of moisture in the seal between the shield and the bushing terminal. The shield was held in place by a metal washer and nut.

Difficulties may be encountered in using shields on bushings along the Pacific Coast because of the prevailing winds which may drive salt and moisture up under the shield. If this happens it will be impossible for the natural washing action of the wind and rain to clean the surface. In laboratory tests salt accumulation on bushings with mechanical shields was not noticeably increased by the action of an electric fan. However, this will be checked by results of the field test being conducted on several shields placed on bushings at the Pacific Coast.

B. Low-Coefficient of Expansion Glasses - The discovery of the fact that the chipping and pitting of both glass and porcelain bushings is due to thermal shock has led to the testing of glasses having various thermal coefficients of linear expansion. Figure X shows the results of a one-week salt fog run on five glass rods 1/4 inches in diameter by eight inches long. As may be observed from Figure X, the lower the coefficient of linear expansion, the less the surface deterioration.

These results are confirmed by observed differences in the amount of tracking on porcelain and glass bushings. Figure IX shows the results of a salt fog run on glazed and unglazed porcelain bushings together with an amber glass bushing. All bushings having identical contours. The glaze, which has a lower coefficient of expansion than the glass, is more resistant to heat shock. It would therefore require more heat before flaking would occur and would flake less than the glass if both were subjected to the same temperature changes.

The principal objections to the use of low expansion glass as a solution to the problem is the high cost of the glass and the difficulty in finding a metal with a coefficient to match the glass. It is not believed to be impossible, but would require considerable time and expense.

C. Inorganic Coatings - Numerous materials with non-wetting characteristics were applied to glass bushings with little success. The materials tried consisted of Dri-Film, A50P78 varnish, Krylon, PVC, Polyethylene and Cetyl-trimethylammonium bromide. All of these coatings showed some short-time improvement. Eventually, however, they all burned off in spots and were generally unsatifactory.

Silicone rubber was applied to a standard amber glass bushing with some good results. The arcing was greatly reduced, and therefore so was the surface deterioration. One bad feature of this coating was its very poor adhesion. It was very easily scraped off.

The recent development of a method for placing Teflon, an inert plastic material, in a liquid suspension has made it possible to apply this material to a glass bushing. The adhesion properties of this material appear to be much better than those of the Silicone rubber.

Figure XI shows the results of a four week test run at 2.5 kv for a Teflon coated bushing and a standard amber glass bushing. No tracking or pitting of the Teflon coated bushing may be observed. Some slight discoloration of the coating is apparent, but this is not believed to be harmful. After being on test an additional two weeks from the time the photograph of Figure XI was taken, there was still no change in the condition of the coating.

D. Semi-Conducting Surface Coatings and Glazes - Reports have frequently arrived in this country of the satisfactory use of semi-conducting glazes on insulators operating in polluted atmospheres in Great Britain. The control of voltage gradient by semi-conducting glazes which conduct leakage and capacity currents at a controlled rate and so prevent unstable discharges is not a particularly new idea. Several patent applications are on record. The difficulty is one of developing a successful glaze. This is because semi-conductors usually have a decided negative temperature coefficient, a mixed blessing which contributes to their value in stabilizing surface films of dirt and moisture but renders them liable to self-destruction in their effort to effect compensation during prolonged and extremely severe conditions of service.

An attempt to grade the field of a standard amber glass bushing by external resistance gave very poor results. This is shown in Figure XII (a).

Several attempts were made to operate a Rescon-coated 5 kv amber glass bushing in a salt fog. The results to date have been largely unsuccessful. This has been due principally to the non-uniformity of the resistance coatings. An example of this is the Rescon coated, sand-blasted 5 kv amber glass bushing tested in Run No. 14. This bushing operated satisfactorily for approximately twelve days with no arcing or surface tracking. However, by the end of this time the combination of heat produced by the flow of leakage current through the Rescon and the inherent negative temperature coefficient of the Rescon coating caused the resistance to drop. It dropped to such a low value that the bushing failed by fracture, as may be seen in Figure XII (b).

Further work is planned along this line of attack. Several types of semi-conducting coatings, having various resistance values, are being applied, by Dr. Spooner, to porcelain and glass bushings. These samples will be tested in the fog chamber and reported later.

E. Bushing Contour - The results of tests conducted in a salt fog on both glass and porcelain bushings of various voltage ratings, and contours (Figure XIII) all point towards one conclusion: Within practical limits there is no size or contour or combination of the two which will entirely prevent arcing, salt deposits or surface deterioration. Some difference in the severity of

deterioration may, however, result from differences in materials, such as glass and porcelain, etc. and from large differences in the length of creepage paths as shown in Figure XIII.

A good example is the improved performance obtained by the operation of a modified contour glass bushing, shown in Figure XIV, in a salt fog. Incorporated in this contour design were horizontal petticoat undercuts. This was done for the purpose of approaching a drip contour as closely as practicable.

Figure IV shows a field map of a dry 5 kv modified contour glass bushing with special imbedded electrostatic shields at both the top and bottom of the bushing. These shields reduce the normally high stress at the terminal and ground flange and give the bushing a more uniform voltage distribution. Figures XV (a) and (b) show the models used to obtain the field maps of a standard contour glass bushing and a modified contour glass bushing.

The results of tests conducted on modified contour glass bushing with both shields, top shield only, bottom shield only, and no shields are shown in Figure VIII. These results show that no particular advantage can be attributed to the use of the imbedded shields. A field test is now in progress on several of these bushings which should help to clarify the question of the value of the shields. These shields would be of definite benefit if the bushing were operating in an area where the contaminant was deposited dry. In such an application the improved voltage distribution would not be impaired by water on the surface.

F. Miscellaneous

1. Bushing Position - Figure XVI (b) shows the results of a salt fog run on an inverted 5 kv amber glass bushing. The object of this test was to determine whether operation could be improved by eliminating gravity as a factor in the deposition of salt and moisture on the surface. The results showed conclusively that nothing was to be gained by inverting the bushing.

2. Internal Heating - Figure XVI (c) shows the results of a salt fog run on an internally heated 5 kv amber glass bushing. The temperature rise over ambient at the surface was 15 C. The results were very satisfactory in that there was no arcing or surface deterioration. The prohibitively high year-round power loss which would result from this arrangement, however, rules out this solution to the problem.

Summary of Results of Salt-Fog Tests

Run No. 1 9/3/48 to 9-13-48, Test time - 11 days at 2.5 kv
Salt fog contained 10% NaCl by weight.

	Test Bushings	Results
(a)	5 kv G.E. amber glass	-Frequent arcing, very light scattered tracking
(b)	5 kv Pheonix glass	-Very frequent arcing, no tracking
(c)	5 kv G.E. amber glass A50P69 varnish coated	-Coating badly burned in spots, scattered light tracking
(d)	5 kv G.E. amber glass with rubber shield	-No arcing, tracking or salt deposits
(e)	5 kv G.E. porcelain	-Frequent arcing, no tracking
(f)	Unenergized 5 kv glass	-No salt deposits

Run No. 2 10-19-48 to 10-28-48, Test time - 10 days at 2.5 kv
Salt fog contained 10% NaCl by weight.

	Test Bushings	Results
(a)	5 kv G.E. porcelain (Continuation of Run 1)	-Frequent arcing, no tracking
(b)	5 kv G.E. glass Polyethylene coated	-Coating badly burned in spots, scattered light tracking
(c)	PVC coating on top two petticoats of 5 kv glass glass	-Coating badly burned in large areas, scattered light tracking
(d)	5 kv G.E. glass with glass shield	-No arcing, tracking or salt deposits
(e)	5 kv G.E. glass with copper shield	-No arcing, tracking or salt deposits
(f)	Unenergized 5 kv G.E. glass	-No salt deposits

Run No. 3 11-12-48 to 12-3-48, Test time - 18 days at 2.5 kv
Salt fog contained 10% NaCl by weight.

	Test Bushings	Results
(a)	5 kv G.E. porcelain (Continuation of Run 1)	-Frequent arcing, very light tracking at terminal
(b)	5 kv G.E. glass with rubber shield	-No arcing, tracking or salt deposits
(c)	5 kv G.E. glass with glass shield	-No arcing, tracking or salt deposits
(d)	5 kv G.E. glass with copper shield	-No arcing, tracking or salt deposits
(e)	5 kv G.E. green, 1075 glass	-Frequent arcing, light tracking around terminal and ground flange
(f)	5 kv G.E. amber glass	-Frequent arcing, light tracking around terminal and ground flange
(g)	5 kv G.E. glass coated with Silicone rubber	-Frequent arcing, no tracking

Run No. 3 (cont'd) 11-2-48 to 12-3-48, Test time - 18 days at 2.5 kv
Salt fog contained 10% NaCl by weight.

	Test Bushings	Results
(h)	15 kv smooth contour G.E. porcelain	-Frequent arcing, no tracking
(i)	5 kv G.E. glass with shunting resistors	-Very frequent arcing, heavy tracking on entire surface

Run No. 4 12-6-48 to 1-29-49, Test time - 54 days at 2.5 kv
Salt fog contained 10% NaCl by weight.

Test Bushings	Results
Nine standard 5 kv G.E. amber glass bushings placed in different positions in the test chamber every nine days	Consistent comparable results were obtained on test samples placed anywhere in the chamber within approximately one foot from the walls and bottom

Run No. 5 2-8-49 to 3-8-49, Test time - 38 days at 2.5 kv
Salt fog contained 10% NaCl by weight.

	Test Bushings	Results
(a)	5 kv G.E. amber glass	-Frequent arcing, medium tracking around terminal and bottom flange
(b)	5 kv G.E. Krylon coated amber glass	-Frequent arcing, coating badly burned away, medium tracking
(c)	5 kv G.E. glass with internal heater (15C surface temp. rise over ambient)	-Very heavy salt deposits, no tracking
(d)	Modified contour 5 kv G.E. glass with standard metal parts	-Very infrequent arcing, scattered light tracking
(e)	Inverted 5 kv G.E. glass	-Frequent arcing, scattered medium tracking
(f)	8.7 kv G.E. amber glass	-Frequent arcing, light tracking around ground flange
(g)	5 kv G.E. black glass	-Frequent arcing, light tracking around terminal and ground flange
(h)	Modified contour 5 kv G.E. black glass	-Infrequent arcing, light tracking around ground flange
(i)	5 kv G.E. glass with Rescon on last petticoat near ground flange	-Frequent arcing, Rescon coating flaked off
(j)	5 kv G.E. glass with Rescon coating, 5000M/□	-Frequent arcing, Rescon coating flaky and loose

Run No. 5 (cont'd) 2-8-49 to 3-8-49, Test time - 38 days at 2.5 kv
Salt fog contained 10% NaCl by weight.

	Test Bushings	Results
(k)	5 kv G.E. glass with Rescon coat over first two petticoats from terminal, 500M/□ No coating on third, and remainder of surface coated with Rescon 5000M/□	-Heavy salt deposit on uncoated petticoat, very frequent arcing medium tracking on uncoated petticoat
(l)	Rescon coated sand blasted 5 kv G.E. amber glass	-Good coating adhesion. Bushing fractured

Run No. 6 3-18-49 to 4-22-49, Test time - 36 days at 2.5 kv
Salt fog contained 10% NaCl by weight.

	Test Bushings	Results
(a)	5 kv G.E. amber glass (Continuation Run 5)	-Frequent arcing, heavy tracking at terminal terminal and ground flange. For 64 day period, 2508 current surges above 10 milliamps were recorded
(b)	5 kv G.E. glass with internal heater	-Heavy salt deposits, no tracking
(c)	Inverted 5 kv G.E. glass	-Frequent arcing, medium tracking near terminal
(d)	Modified contour 5 kv G.E. black glass, St'd metal parts (Continuation of Run 5)	-Frequent arcing, heavy tracking at small diameters between every petticoat
(e)	Modified contour 5 kv G.E. glass with special metal parts	-Frequent arcing, medium tracking around ground flange, light tracking at terminal
(f)	5 kv "C-D" porcelain	-No arcing, tracking or salt deposits
(g)	5 kv "W" porcelain	-No arcing, tracking or salt deposits
(h)	8.7 kv "C-D" porcelain	-No arcing, tracking or salt deposits
(i)	8.7 kv "W" porcelain	-No arcing, tracking or salt deposits

Run No. 7 4-26-49 to 5-24-49, Test time - 28 days at 2.5 kv
Salt fog contained 10% NaCl by weight.

	Test Bushings	Results
(a)	through (d) are continued from Run 6	
(a)	5 kv "C-D" porcelain	-No arcing, tracking, or salt deposits
(b)	5 kv "W" porcelain	-Frequent arcing over straight section Some light tracking in this area
(c)	8.7 kv "C-D" porcelain	-No arcing, tracking or salt deposits
(d)	8.7 kv "W" porcelain	-No arcing, tracking or salt deposits

Run No. 8 6-10-49 to 7-1-49, Test time - 21 days at 2.5 kv.
Salt fog contained 10% NaCl by weight.

Test Bushings	Results
Two 5 kv G.E. amber glass bushings Purpose: To determine when tracking begins	-This proved to be quite difficult as the surface deterioration begins with the removal of microscopic chips of glass. No definite results were obtained. However, arcing and the build-up of salt deposits were found to start within one or two hours after the salt fog was first admitted into the test chamber.

Run No. 9 11-1-49 to 11-8-49, Test time - 7 days at 5 kv the first day and 2.5 kv for the remaining six days. By weight salt fog contained 10% NaCl, 1.2% $MgCl_2$, .8% $MgSO_4$, .5% $CaSO_4$, and .02% KCl.

	Test Bushings	Results
(a)	5 kv G.E. amber glass	-Heavy tracking over entire bushing
(b)	5 kv G.E. porcelain	-Heavy tracking around bottom
(c)	5 kv "W" porcelain	-Medium tracking
(d)	5 kv "C-D" porcelain	-Large section of third petticoat from top was removed by chipping

Run No. 10 11-9-49 to 11-11-49, Test time - 48 hours at 5 kv.
Salt fog contained same salts as in Run 9 with the exception of $MgCl_2$ by weight.

Test Bushing	Results
5 kv G.E. amber glass	-Scattered light tracking

Run No. 11 11-11-49 to 11-13-49, Test time - 48 hours at 5 kv.
Salt fog contained 10% NaCl and 1.2% $MgCl_2$ by weight.

Test Bushing	Results
5 kv G.E. amber glass	-Medium tracking on lower half of bushing near ground flange

Run No. 12 11-13-49 to 11-15-49, Test time - 48 hours at 5 kv.
Salt fog contained 10% NaCl and .3% $CaSO_4$ by weight,

Test Bushing	Results
5 kv G.E. amber glass	-Very light scattered tracking

Run No. 13 11-15-49 to 11-16-49, Test time - 32 hours at 5 kv.
Salt fog contained 1.2% $MgCl_2$ by weight.

Test Bushing	Results
5 kv G.E. glass bushing	-Heavy scattered tracking

Run No. 14 11-16-49 to 11-29-49, Test time - 13 days at 5 kv.
Salt fog contained 10% NaCl and 1.2% $MgCl_2$ by weight

	Test Bushing	Results
(a)	5 kv G.E. glass with special high resistance coating	-Non-uniform resistance of coating resulted in scattered heavy tracking. Removed from test after 4 days
(b)	5 kv G.E. glass with Rescon coat, 10M/□	-Operation good until runaway characteristics of coating caused sufficient heat to be generated and fracture bushing.

Run No. 15 11-17-49 to 12-8-49, Test time - 21 days at 5 kv.
Salt fog contained 10% NaCl and 1.2% $MgCl_2$ by weight

	Test Bushing	Results
(a)	Rubber shield on 5 kv G.E. amber glass	-Rubber cracked and allowed water to flow down surface. Scattered heavy tracking
(b)	Silicone rubber coated 5 kv G.E. amber glass	-Arcing frequency increased with time and removed rubber in spots. Light tracking. Removed from test after 12 days.

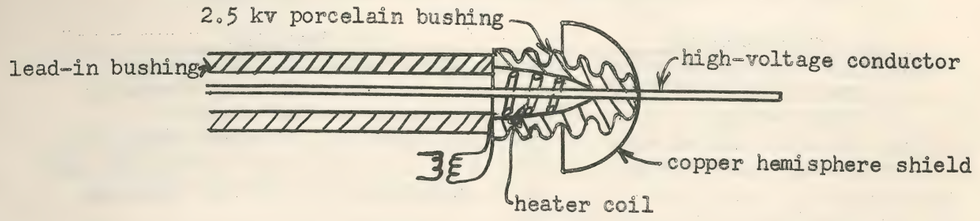
Run No. 16 11-29-49 to 12-9-49, Test time - 9 days at 5 kv.
Salt fog contained 10% NaCl and 1.2% $MgCl_2$ by weight

Test Bushing	Results
Permafil coated 5 kv amber glass	-Arcing frequency increased with time and removed coating in spots. Scattered medium tracking

Run No. 17 12-8-49 to 12-15-49, Test time - 7 days at 1 kv for the first five days and 2.5 kv for the last 2 days. Salt fog contained 10% NaCl and 1.2% $MgCl_2$ by weight

Rod Diameter	Coefficient of Linear Expansion $\times 10^{-6}$	Results
(a) 1/4 inch	5.5	-No appreciable difference in the amount of tracking was observed. However, sample (a) had slightly more tracking than (f). On all, tracking was scattered from one end of the rod to the other.
(b) 1/4 inch	5.03	
(c) 1/4 inch	4.62	
(d) 1/4 inch	4.04	
(e) 1/4 inch	3.69	
(f) 5/16 inch	3.38	

Run No. 18 12-16-49 to 1-2-50, Repaired chamber



Repaired leaks and modified the high voltage lead-in bushing which was badly tracked and even chipped at end. The modification made is shown in sketch above. The heating coil keeps the surface dry by raising to 90° the surface temperature of the porcelain on the end. The shield reduces the normally high stress at the end. This bushing collects salt but no more arcing or etching has been observed.

Run No. 19 1-3-50 to 1-9-50, Test time - 7 days at 5 kv.
Salt fog contained 10% NaCl and 1.2% $MgCl_2$ by weight

Test Bushings	Results
(a) Modified contour 5 kv amber glass	-Scattered heavy tracking
(b) Modified contour 5 kv G.E. glazed porcelain	-Scattered light tracking
(c) Modified contour 5 kv G.E. unglazed porcelain	-Section of porcelain at edge of first petticoat chipped. Several areas of cracked porcelain

Run No. 20 1-10-50 to 1-17-50, Test time - 7 days at 5 kv.
Salt fog contained 10% NaCl and 1.2% $MgCl_2$ by weight

Test Bushing	Creepage Path -In.	Strike Dist. In.	Strike Dist. Less Shield	Results
(a) 2.5 kv G.E. glass	4.25	3.125	--	-Scattered Heavy tracking
(b) 2.5 kv G.E. glass with rubber shield	4.5	--	1.375	-Rubber burned in spots, some tracking
(c) 5 kv G.E. glass	6.25	4.5	--	-Heavy tracking at bottom
(d) 5 kv G.E. glass with rubber shield	6.25	--	2.75	-Rubber burned in spots, some tracking
(e) 8.7 kv G.E. glass	8.25	6	--	-Heavy tracking at bottom
(f) 8.7 kv G.E. glass with rubber shield	8.25	--	4.25	-Rubber burned in spots, some tracking

Run No. 20 (Cont'd) 1-10-50 to 1-17-50, Test time - 7 days at 5 kv.
Salt fog contained 10% NaCl and 1.2% $MgCl_2$ by weight,

Test Bushing	Creepage Path-In.	Strike Dist. In.	Strike Dist. Less Shield	Results
(g) Modified contour 5 kv glass, modified metal parts	9	6.75		-Heavy tracking between 4th and 5th petticoats
(h) Modified contour 8.7 kv glass	8.25	6		-Scattered medium tracking
(i) 15 kv G.E. glass	14.5	9.25		-Scattered light tracking at middle and bottom
(j) 5 kv modified contour glass st'd hardware	9	6.75		-Heavy tracking bottom half of bushing
(k) 5 kv modified contour glass top internal shield only	9	6.75		-Medium tracking around top and bottom of bushing
(l) 5 kv modified contour glass bottom internal shield only	9	6.75		-Heavy tracking around bottom of bushing
(m) 5 kv modified contour glass, st'd metal parts and an external ground ring	9	6.75		-Heavy tracking around bushing just above ground ring

Run No. 21 1-17-50 to 1-24-50, Test time - 7 days at 5 kv.
Salt fog contained 10% NaCl and 1.2% $MgCl_2$ by weight.
Five 1/4 inch diameter glass rods eight inches long.

Rod Material	Coefficient of Linear Expansion x 10^{-6}	Results
(a) Lime glass	9.2	-Severe tracking over entire length of rod
(b) #0-33 amber glass	5.5	-Scattered heavy tracking
(c) PLF-3 amber glass	5.5	-Scattered heavy tracking
(d) Pyrex glass	3.2	-Scattered light tracking
(e) Vycor glass	0.8	-Very light tracks

Run No. 22 1-24-50 to 1-31-50, Test time - 7 days at 5 kv.
Salt fog contained 10% NaCl and 1.2% $MgCl_2$ by weight.

Test Bushings	Creepage Path-In.	Strike Dist. In.	Results
(a) 5 kv G.E. porcelain	6.75	5.25	-Heavy tracking at top and bottom
(b) 5 kv "C-D" porcelain	7.375	5.25	-Heavy tracking at top
(c) 5 kv "W" porcelain	5.5	5	-Light tracking at top and on straight section
(d) 8.7 kv "C-D" porcelain	11.5	6.75	-Medium tracking at bottom
(e) 15 kv G.E. drip contour porcelain	11	7.75	-Heavy tracking at bottom
(f) 15 kv G.E. smooth contour porcelain	9.75	7.25	-Heavy tracking at bottom
(g) 2.5 kv G.E. porcelain	4.5	3.5	-Heavy tracking and burned appearance of glaze at top

Run No. 23 2-6-50 to 3-6-50, Test time - 28 days at 5 kv.
Salt fog contained 10% NaCl and 1.2% $MgCl_2$ by weight.

Test Sample	Results
(a) Proposed 15 kv Type L glass bushing shell	-Very heavy tracking and considerable fracturing of the glass
(b) Unglazed porcelain with contour of proposed 15 kv Type L glass bushing shell	-Several large chips of porcelain removed. A few heavy tracks
(c) Glazed porcelain with contour of proposed 15 kv Type L glass bushing shell	-Very light tracking at top and bottom
(d) 3/8 in. dia. Pyrex glass rod 4 inches long	-Medium tracking over entire length
(e) 3/8 in. dia. Pyrex glass rod 6 inches long	-Light tracking at high voltage end
(f) 3/8 in. dia. Pyrex glass rod 8 inches long	-Scattered light tracks

Run No. 24 4-12-50 to 4-17-50, Test time - 35 days at 2.5 kv.
Salt fog contained 10% NaCl and 1.2% $MgCl_2$ by weight.

Test Bushings	Results
(a) 5 kv G.E. amber glass	-Scattered heavy tracking
(b) 5 kv G.E. amber glass coated with Krylon	-Coating burned off in very short time. Sample removed from test after two weeks.
(c) 5 kv G.E. amber glass with neoprene rubber shield not water tight at terminal	-Salt deposits under shield, considerable light tracking and burning of shield
(d) 5 kv G.E. amber glass with neoprene rubber shield water tight at terminal	-Excellent results, bushing and shield in same condition as when placed on test
(e) 5 kv Line Material porcelain	-Medium burning and tracking of glaze around terminal and ground flange

Run No. 24 (Cont'd) 4/12/50 to 4/17/50, Test time - 35 days at 2.5 kv.
Salt fog contained 10% NaCl and 1.2% $MgCl_2$ by weight.

Test Bushings	Results
(f) 5 kv G.E. porcelain	-Medium tracking, large areas of glaze removed on top petticoat and around bottom of bushing

Run No. 25 4/27/50 to 6/20/50, Test time - 55 days at 5 kv.
Salt fog contained 10% NaCl and 1.2% $MgCl_2$ by weight.

Test Bushings	Results
(a) 5 kv G.E. amber glass coated with Teflon	-Salt deposits on bushing - light No tracking of removal of Teflon coating. Some discoloration was observable
(b) 5 kv G.E. amber glass with neoprene rubber shield water tight at terminal	-Rubber shield cracked around terminal in two days. Removed from test
(c) 5 kv G.E. sand blasted amber glass with R402 coating	-Coating burned off in two weeks on test

FIGURE I-A 5 KV AMBER GLASS BUSHING AFTER OPERATING FOUR WEEKS IN A SALT FOG CONTAINING TEN PERCENT SODIUM CHLORIDE BY WEIGHT.

FIGURE I-B 5 KV AMBER GLASS BUSHING AFTER OPERATING ONE WEEK IN A SALT FOG CONTAINING 10 PERCENT SODIUM CHLORIDE PLUS 1.2 PERCENT MAGNESIUM CHLORIDE BY WEIGHT.

PL-32633

PORCELAIN BUSHINGS

A – 5 KV G.E.

B – 5 KV "W"

C – 5 KV "C-D"

GLASS BUSHINGS

D – 8.7 KV G.E.

E – MODIFIED CONTOUR 5 KV G.E.

FIGURE II

CHARACTERISTIC SALT DEPOSITS ON
GLASS & PORCELAIN BUSHINGS

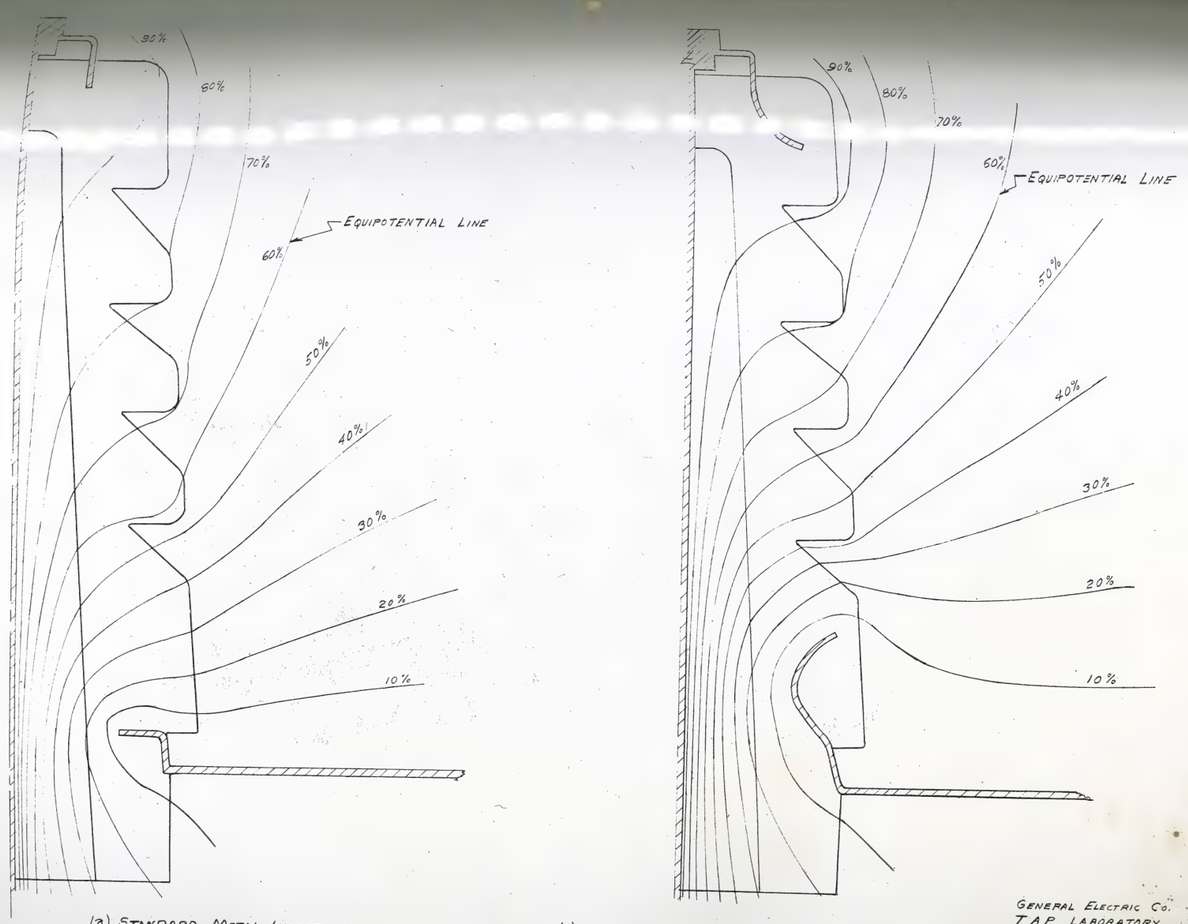
PL-32639

101 HC675

(b) STANDARD WITH EXTERNAL COPPER SHIELD

(a) STANDARD

FIGURE III FIELD MAPS OF STANDARD 5 KV GLASS BUSHINGS



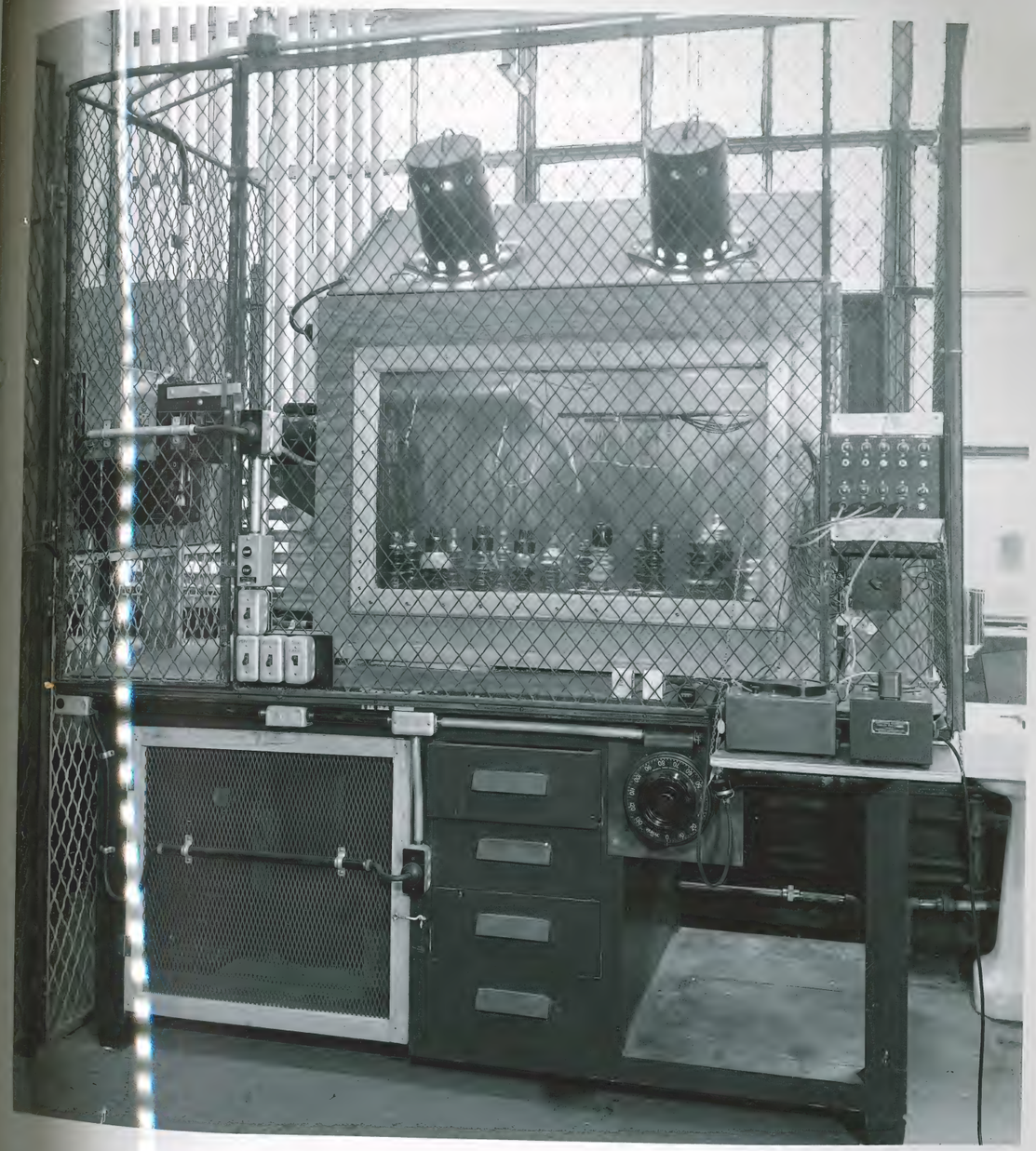
(a) STANDARD METAL INSERTS

(b) IMBEDED ELECTROSTATIC SHIELDS

FIGURE IV FIELD MAPS OF MODIFIED CONTOUR 5 KV GLASS BUSHINGS

GENERAL ELECTRIC CO.
TAP LABORATORY
ELECTRICAL RESEARCH SECTION (612)
R. Bass Jr. June 13, 1950
7-10-50

101 HC 676



3009 842 FOG CHAMBER AND ASSOCIATED EQUIPMENT.

Transformer and Allied Product Divisions

Figure 5 E369.4 11-22-48

A-5 KV GENERAL ELECTRIC

B-5 KV WESTINGHOUSE

C-8.7 KV WESTINGHOUSE

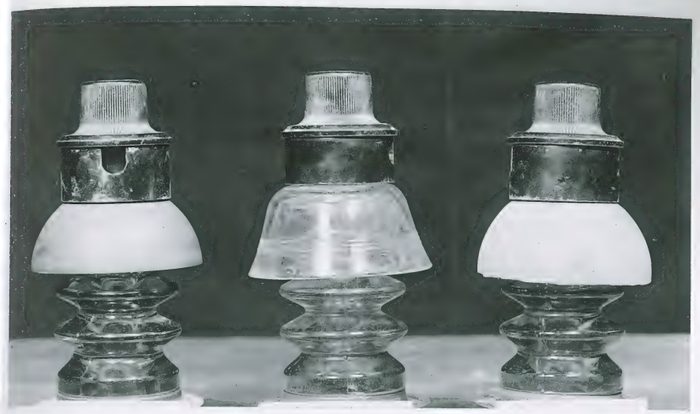
D-15 KV GENERAL ELECTRIC

E-15 KV G.E.

F-8.7 KV CORNELL-DUBILIER

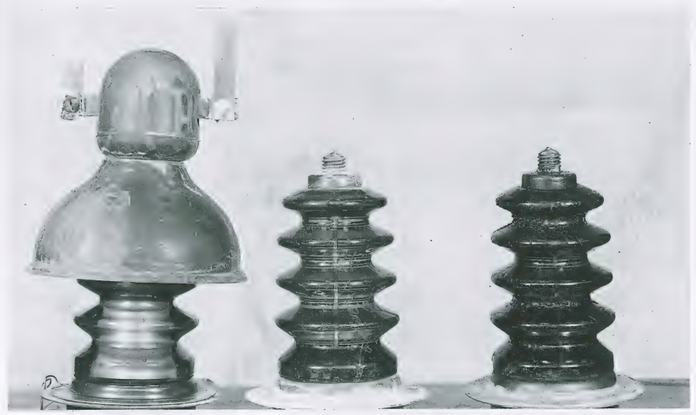
FIGURE II RESULTS OF A STANDARD EIGHT HOUR CARBON RUN ON VARIOUS PORCELAIN BUSHINGS.

PL-32638



A- COPPER B- GLASS C-RUBBER

FIGURE VII TYPES OF MECHANICAL SHIELDS USED ON 5 KV AMBER GLASS BUSHINGS.



A- TYPE SHIELD B-WATER TIGHT C- NOT WATER TIGHT

FIGURE VIII RESULTS OF SALT RUN ON 5 KV AMBER GLASS BUSHINGS WITH NEOPRENE RUBBER SHIELDS, WATER TIGHT AND NOT WATER TIGHT AT TERMINAL.

PL-32637

A - AMBER GLASS

B - UNGLAZED PORCELAIN

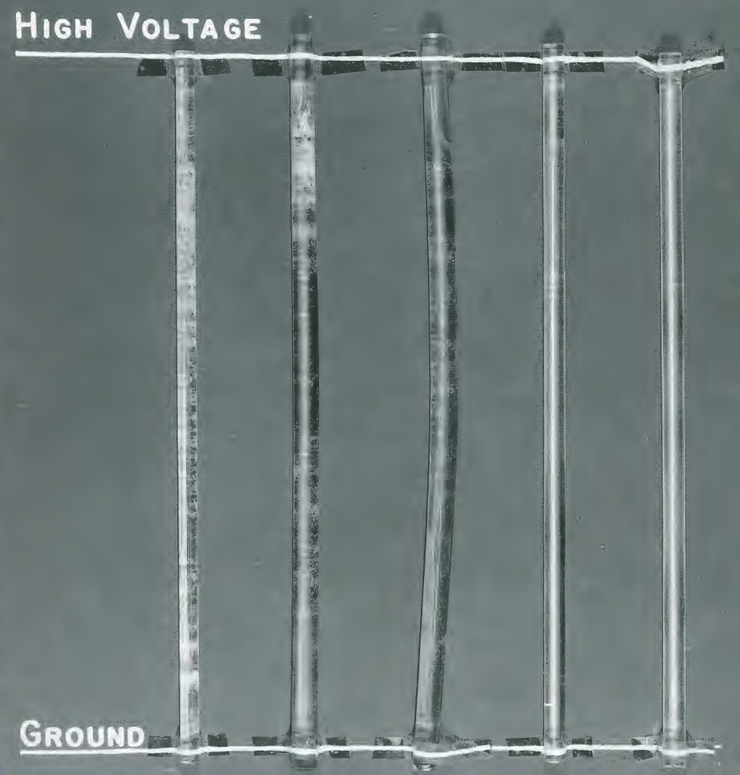
C - GLAZED PORCELAIN

FIGURE IX RESULTS OF A SALT RUN ON 5 KV MODIFIED CONTOUR BUSHINGS.

PL-32632

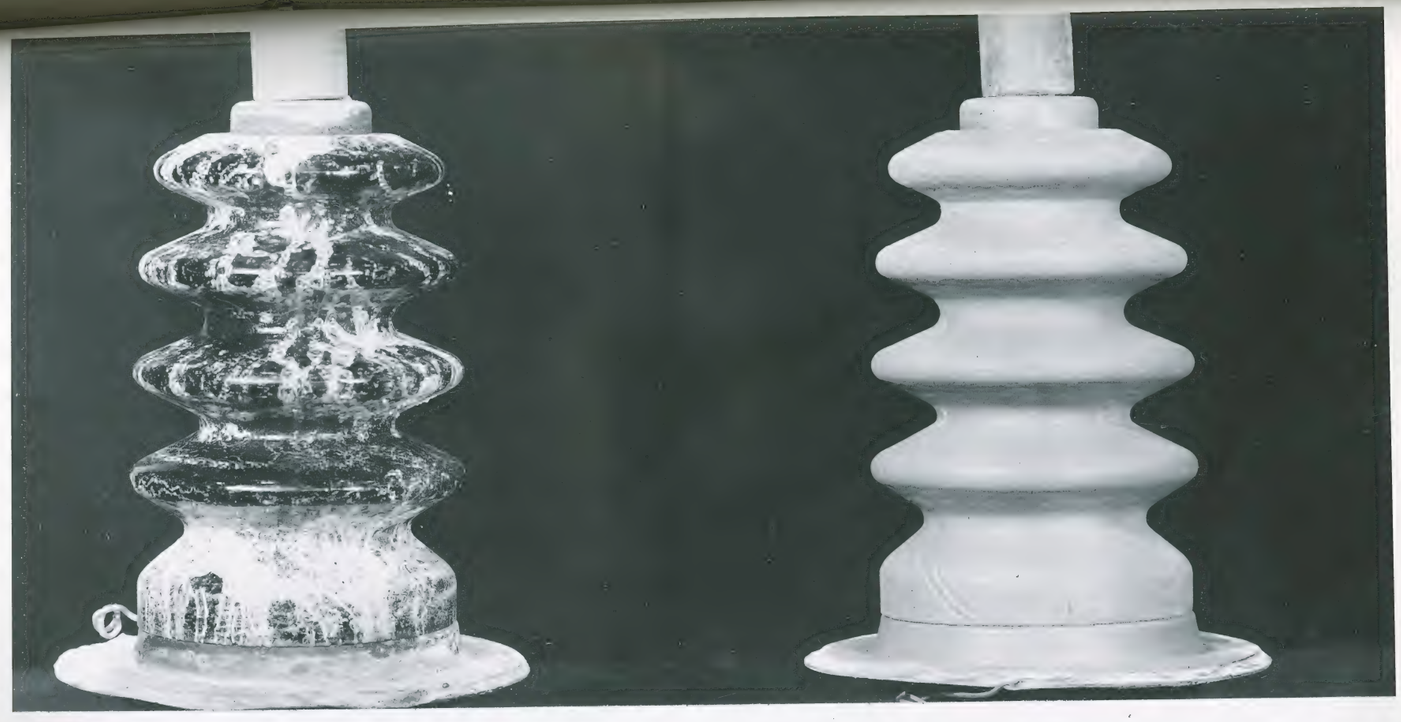
FIGURE X

RESULTS OF A SALT SPRAY RUN OF ONE WEEK ON GLASS RODS OF VARIOUS THERMAL COEFFICIENTS OF LINEAR EXPANSION



GLASS — LIME	# 0-33	PL F-3	PYREX	VYCOR
COEFFICIENT OF LINEAR EXPANSION - 9.2 TIMES 10^6	5.5	5.5	3.2	0.8

PL-32555



A — STANDARD BUSHING

B — TEFLON COATED BUSHING

FIGURE XI — RESULTS OF SALT RUN ON 5KV AMBER GLASS BUSHINGS.

PL-32630

FIGURE XII - A 5 KV AMBER GLASS BUSHING WITH SHUNTING RESISTORS FOR VOLTAGE GRADING, AFTER A SALT RUN.

FIGURE XII - B 5 KV SAND-BLASTED AMBER GLASS BUSHING WITH RESCON COATING, AFTER A SALT RUN.

PL-32631

PORCELAIN BUSHINGS

A- 5 KV G.E. B-5 KV "L.M." C- 5 KV "W" D-5 KV "C-D"

G.E. GLASS BUSHINGS

E-"150 BIL" F—PROPOSED 15 KV TYPE L SHELL G- 5 KV H-8.7 KV

FIGURE XIII RESULTS OF SALT RUNS ON GLASS & PORCELAIN BUSHINGS OF VARIOUS SIZES & CONTOURS.

PL-32635

A – SHIELDS TOP AND BOTTOM

B – NO SHIELDS

C – TOP SHIELD ONLY

D – BOTTOM SHIELD ONLY

FIGURE XIV RESULTS OF SALT RUN ON 5 KV MODIFIED CONTOUR AMBER GLASS BUSHINGS WITH & WITHOUT EMBEDDED ELECTROSTATIC SHIELDS.

PL-32636

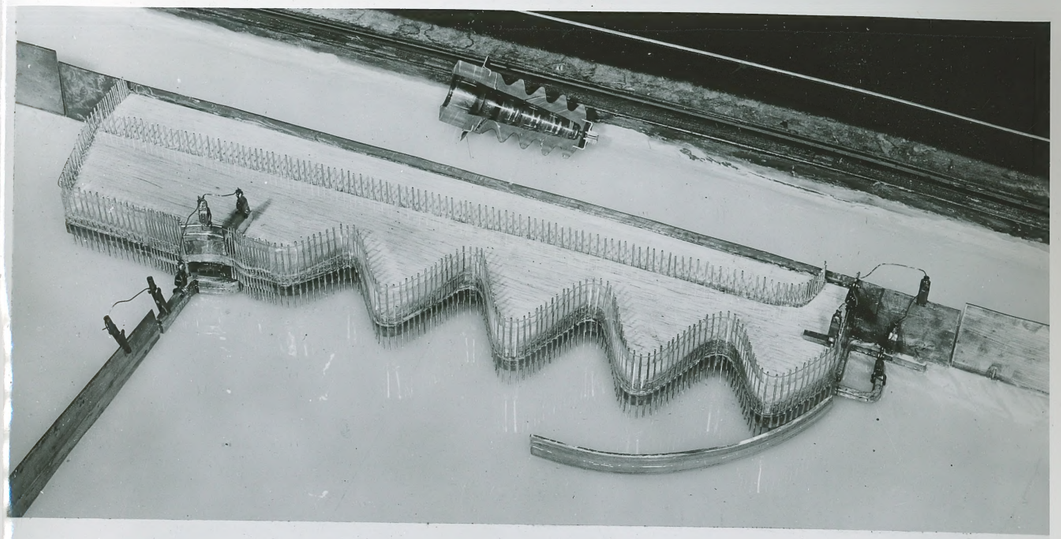


FIGURE XV-A MODEL OF 5 KV CENTRIFUGALLY CAST AMBER GLASS BUSHING WITH SHIELD IN ELECTROLYTIC TANK.

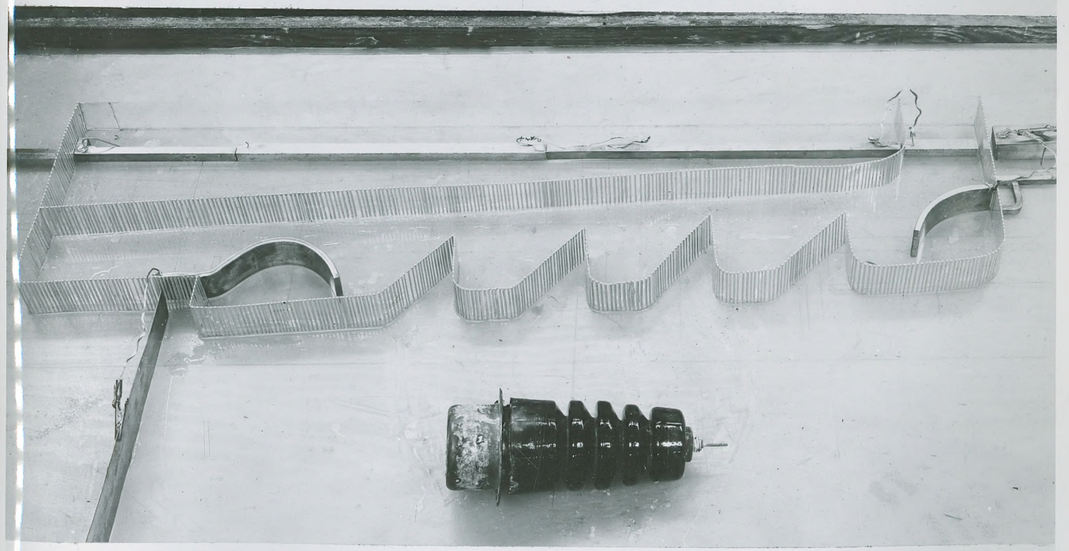
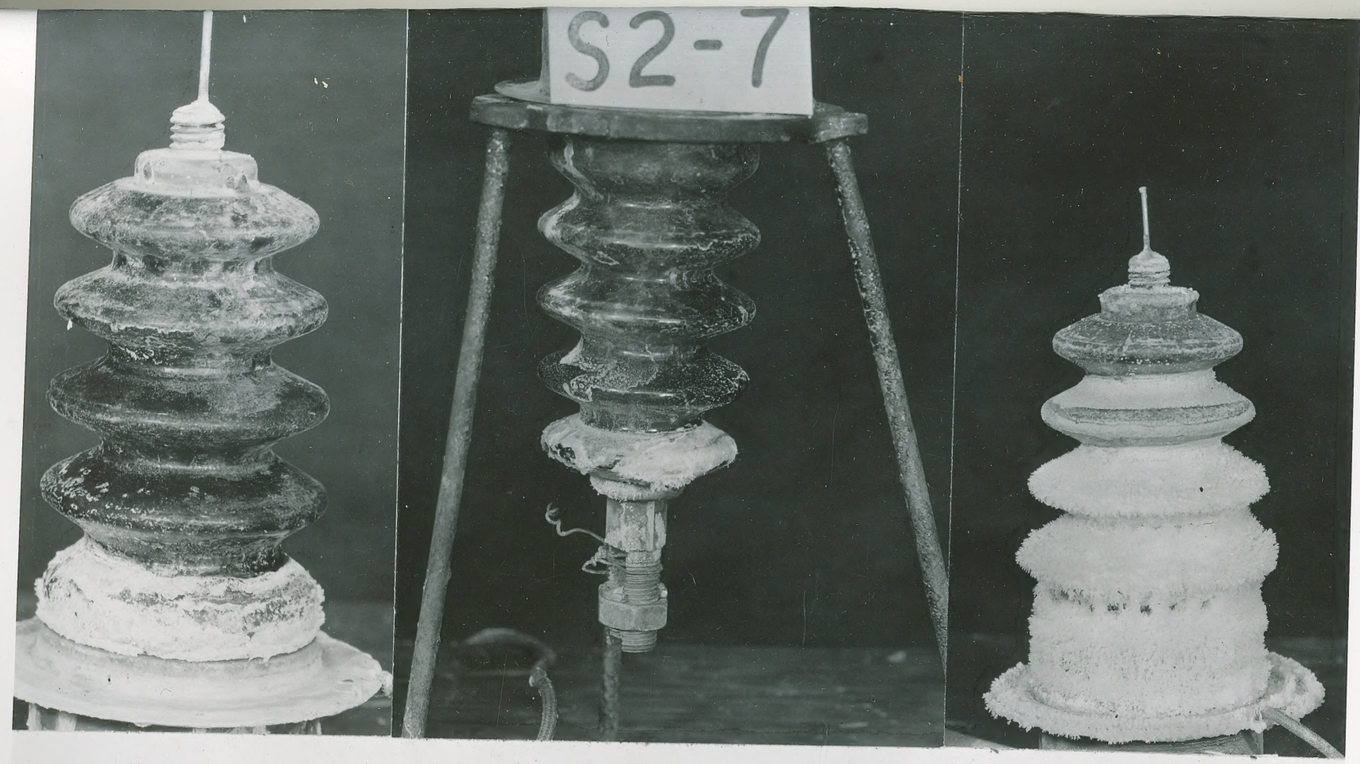


FIGURE XV-B MODEL OF MODIFIED CONTOUR 5 KV CENTRIFUGALLY CAST AMBER GLASS BUSHING WITH SPECIAL METAL PARTS IN ELECTROLYTIC TANK.

PL-32634



A— STANDARD BUSHING B — BUSHING INVERTED C— INTERNAL HEATING

FIGURE XVI RESULTS OF SALT RUNS ON 5 KV AMBER GLASS BUSHINGS.

PL-32629